NPS-AM-13-013

ACQUISITION RESEARCH
CASE STUDY

Real Options in Military System Acquisition: The Case Study of Technology Development for the Javelin Anti-Tank Weapon System

22 August 2013

Dr. Diana Angelis, Associate Professor
Defense Resource Management Institute

Dr. David N. Ford, Research Associate Professor
John Dillard, Senior Lecturer
Graduate School of Business & Public Policy

Naval Postgraduate School

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
22 AUG 2013

2. REPORT TYPE

3. DATES COVERED
00-00-2013 to 00-00-2013

4. TITLE AND SUBTITLE
Real Options in Military System Acquisition: The Case Study of Technology Development for the Javelin Anti-Tank Weapon System

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School,Graduate School of Business & Public Policy,Monterey,CA,93943

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Three different technologies were considered in the technology development phase of the Javelin anti-tank missile system: a laser-beam riding system, a fiberoptic system, and a forward looking infrared system. The Army awarded three ?Proof of Principle? contracts to three competing contractor teams to develop and conduct a ?fly-off? technology competition. The current work analyzed the three alternatives using measures of effectiveness (MOE) to combine performance across nine acquisition objectives. These MOEs were compared with development and procurement cost estimates. No alternative dominated. Marginal benefits analysis was next used to define the trade?off space among the alternatives. Differences in the likelihood of successful development of the alternatives were evaluated, resulting in one technology appearing to dominate. However, the acquisition approach created a real option for the best alternative that could differentially add value to the alternatives. A real options model was used to analyze the value provided by investing in this competitive option. Results indicate the Army paid less than the total value of the three options, but could have increased net savings by paying different amounts to test each alternative. The analysis method provides a logical and defendable approach to the analysis of alternatives during technology development uncertainty.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**37**	

The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

Abstract

Three different technologies were considered in the technology development phase of the Javelin anti-tank missile system: a laser-beam riding system, a fiber-optic system, and a forward looking infrared system. The Army awarded three “Proof of Principle” contracts to three competing contractor teams to develop and conduct a “fly-off” technology competition. The current work analyzed the three alternatives using measures of effectiveness (MOE) to combine performance across nine acquisition objectives. These MOEs were compared with development and procurement cost estimates. No alternative dominated. Marginal benefits analysis was next used to define the trade–off space among the alternatives. Differences in the likelihood of successful development of the alternatives were evaluated, resulting in one technology appearing to dominate. However, the acquisition approach created a real option for the best alternative that could differentially add value to the alternatives. A real options model was used to analyze the value provided by investing in this competitive option. Results indicate the Army paid less than the total value of the three options, but could have increased net savings by paying different amounts to test each alternative. The analysis method provides a logical and defendable approach to the analysis of alternatives during technology development uncertainty.

Keywords: Real Options, Analysis of Alternatives, Technology Development, Javelin

THIS PAGE INTENTIONALLY LEFT BLANK

About the Authors

Dr. Diana Angelis, associate professor at the Naval Postgraduate School (NPS) Defense Resource Management Institute (DRMI), studied accounting at the University of Florida and received a BS in business administration in 1977 and a BS in electrical engineering in 1985. She received her PhD in industrial and systems engineering from the University of Florida in 1996. She was commissioned an officer in the United States Air Force in 1984 and served as a program engineer until 1989. Dr. Angelis is a certified public accountant and a Lt Col in the U.S. Air Force Reserve. She joined the DRMI faculty in 1996.

Dr. Diana Angelis
Graduate School of Business & Public Policy
Naval Postgraduate School
Monterey, CA 93943-5000
Tel: (831) 656-2051
Fax: (831) 656-3407
E-mail: diangeli@nps.edu

Dr. David N. Ford received BS and MS degrees from Tulane University, New Orleans, LA, and the PhD degree from the Massachusetts Institute of Technology, Cambridge, MA. He is an associate professor and the Urban/Beavers Development Professor in the Zachry Department of Civil Engineering, Texas A&M University, College Station, TX. He also serves as a research associate professor of acquisition with the Graduate School of Business and Public Policy at the U.S. Naval Postgraduate School in Monterey, CA. Prior to joining Texas A&M, he was on the faculty of the Department of Information Science, University of Bergen, Bergen, Norway, where he researched and taught in the System Dynamics Program. For over 14 years, he designed and managed the development of constructed facilities in industry and government. His current research investigates the dynamics of development projects, managerial real options, and sustainability. Dr. Ford is a member of ASCE and other professional organizations.

Dr. David N. Ford
Graduate School of Business & Public Policy
Naval Postgraduate School
Monterey, CA 93943-5000
Tel: (831) 656-2257
Fax: (831) 656-3407
E-mail: DavidFord@tamu.edu

John Dillard, Colonel, USA (Ret) now serves as the academic area chair for Systems Acquisition Management at the Naval Postgraduate School. He joined the Naval Postgraduate School faculty in the fall of 2000 with extensive experience in

the field. His research focuses on defense acquisition policy changes and their implications. Colonel Dillard began a career in defense acquisition after attaining a Master of Science in Systems Management from the University of Southern California in 1985. He then became involved with a myriad of technologies and system concepts that have evolved into fielded products, such as the M-4 Carbine, 120mm Mortar, and M-24 Sniper Weapon. He was the assistant project manager for development of both the Army Tactical Missile System and the Javelin Antitank Weapon System at Redstone Arsenal, AL. These systems incorporate state-of-the-art technologies, are in sustained production and fielding, and are now battle-proven. He was the product manager for the Joint Advanced Special Operations Radio System, and in 1998, was appointed to command the Defense Contract Management Agency office in Long Island, NY. He has furthered his research by serving on panels for the Center for Strategic and International Studies and the National Academy of Sciences.

John Dillard
Graduate School of Business & Public Policy
Naval Postgraduate School
Monterey, CA 93943-5000
Tel: (831) 656-2650
Fax: (831) 656-3407
E-mail: jtdillar@nps.edu

NPS-AM-13-013

ACQUISITION RESEARCH CASE STUDY

Real Options in Military System Acquisition: The Case Study of Technology Development for the Javelin Anti-Tank Weapon System

22 August 2013

Dr. Diana Angelis, Associate Professor
Defense Resource Management Institute

Dr. David N. Ford, Research Associate Professor
John Dillard, Senior Lecturer
Graduate School of Business & Public Policy

Naval Postgraduate School

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

THIS PAGE INTENTIONALLY LEFT BLANK

List of Figures

THIS PAGE INTENTIONALLY LEFT BLANK

List of Tables

THIS PAGE INTENTIONALLY LEFT BLANK

Real Options in Military System Acquisition: The Case Study of Technology Development for the Javelin Anti-Tank Weapon System

Introduction

Anti-tank weapons have been important to meeting Department of Defense objectives since the appearance of armored vehicles on the modern battlefield in World War 1. From the 1960s through 1970s, the M67 90mm recoilless rifle was used as a primary mounted and dismounted infantry weapon against tanks and armored personnel carriers. This weapon was replaced by the DRAGON anti-tank weapon system, introduced in the late 1970s, which had a wired command link that was employed to guide the missile to a target that was optically tracked by the gunner. The DRAGON system had been developed in the 1960s as a response to the Soviet development of the AT-3 SAGGER manpack missile system, carried in a fiberglass container about the size of a small suitcase. But the DRAGON system had reliability problems and limited range and lethality, and it was difficult for gunners to aim the missile and track the target. The goal was to replace DRAGON with a weapon with increased range and lethality and less weight (a later requirement emerged for the ability to be launched from inside an enclosure; e.g., buildings and bunkers). The Advanced Anti-Armor Weapon System–Medium (AAWS–M) project inspired the Javelin program. The joint Army and Marine Corps operational requirements document for the Javelin was formally approved—amended in 1986–88.

Figure 1. The Javelin Anti-tank Weapon System Missile and Command Launch Unit
(Personal communication with US Army Infantry School, Jan, 1992)

The Javelin is a “fire-and-forget” missile. This fire-and-forget capability came from the Joint Army/Marine Corps Source Selection Board’s decision to select the development team’s AAWS–M design, which coupled an imaging infra-red, forward-looking infra-red radar IR (FLIR) system with a beyond state-of-the-art onboard software tracking system.

Figure 2. The Javelin Gunner Looks Through the Command Launch Unit
(Lyons, Long, & Chait, 2006)

Javelin required several immature technologies in order to successfully attain program requirements. A number of the subsystems were based on these immature technologies. For example, the munition required a tandem shaped charge to first set off an explosion to deflect reactive armor defensive systems and then a primary munition for armor penetration and target defeat. The target locating and missile guidance subsystems were particularly troublesome technical issues. Three very different technologies were initially considered in a technology development phase, in order to not constrain the materiel solution to the FLIR approach: a laser-beam riding system, a fiber-optic guided system, and the forward looking infrared system. Each of the three potential technologies generally offered the needed capabilities and represented acquisition options. Rather than choosing a single technology, in August 1986, the Army decided to award three Proof of Principle (technology demonstration phase) contracts of $30 million each to three competing contractor teams to develop the technologies and conduct a “fly-off” missile competition. The Army paid $90 million for these three options that all had potential but none with a guarantee of success. By doing this, the Army acquired the right, but not the obligation, to purchase the most successful technology for the Javelin missile. This comprises the essence of a “real option.”

In this paper, we apply the real option model to the three candidate Javelin guidance technologies. We begin with a short introduction to real options theory

followed by a description of the Javelin guidance technology options. Next, we present a model for measuring the effectiveness of the three guidance technologies and examine the cost effectiveness of each alternative based on “cost per kill” under deterministic and probabilistic assumptions. Finally, we use a decision tree to model the value of each option, given the probability of success and the costs to recover from failure.

Real Options

Real options theory is one means of structuring and valuing flexible strategies to address uncertainty (Courtney, Kirkland, & Viguerie, 1997). An option is a right without an obligation to take specific future actions depending on how uncertain conditions evolve (Brealey & Meyers, 2000). Real options apply options theory to tangible assets. The central premise of real options theory is that, if future conditions are uncertain and changing the strategy later incurs substantial costs, then having flexible strategies and delaying decisions can have value when compared to making all strategic decisions during pre-project planning (Amram & Kulatilaka, 1999). Real options theory helps answer questions such as the following: What are the future alternative actions? When should we choose between these actions to maximize value based on the evolution of conditions? and How much is the right to choose an alternative later worth at any given time?

A real option compares one or more alternative strategies that may be used in the future to a reference strategy that is committed to in the present, if chosen. Conditions are monitored and potentially converted into a signal and compared to trigger conditions using an exercise decision rule to determine if the reference strategy should be abandoned and an alternative strategy adopted (i.e., to “exercise” the option). The waiting to see how uncertainty evolves (i.e., learning) and thereby make better strategy choices is an inherent part of real options. Therefore, delayed decision-making is an important feature of real options. In the classic example of stock purchase options, the exercise decision rule is to buy a stock if the price rises above a certain price, and the exercise signal is the stock price. The decision delay

is incurred while the option holder waits to see if the stock price rises above the exercise price. In real options, one must define both the exercise decision and the exercise signal in the context of a set of observable variables.

Real options can be described along several dimensions, including ownership, the source of value, complexity, and degree to which the option is available. A common topology separates real options according to the type of managerial action applied, including options that postpone (hold and phasing options), change the amount of investment (growth, scaling, or abandonment options), or alter the form of involvement (switching options).

The use of real options can focus on the monetary valuation of the flexibility or on the design and impacts of real options on decision-making in practice (managerial real options). Both of these aspects of real options can improve project management and add value to projects. A wide variety of mathematical models have been used to estimate the monetary value of options, which can be used to select among alternative strategies (e.g., Garvin & Cheah, 2004). These models use the various benefits and costs of an option to estimate its value. Although some real options can be purchased and exercised at no cost (e.g., the option to have salaried employees work overtime), real options become interesting when significant costs are required to obtain, maintain, or exercise the flexibility that may add value. The option cost is what must be paid for access to the flexibility to change the strategy. Option maintenance costs include benefits lost by delaying the strategy choice decision. Option exercise costs are the costs of changing the strategy if the option is exercised. One simple and intuitive approach is to estimate the value of an option as the difference between the values of the project with and without the option (e.g., by assuming uncertainty impacts future performance versus assuming a single specific and known future).

In contrast to a focus on option valuation, a focus on managerial real options works to improve decision-making by structuring risky circumstances faced by practitioners into real options and facilitating option design and implementation. For

example, Ceylan and Ford (2002) describe the use of options to manage technology development risk in the development of the National Ignition Facility by the Department of Energy. Managerial real options address many of the challenges of using real options valuation models to improve risk management (Triantis, 2005; Garvin & Ford, 2012). Structuring development program risk management challenges as real options requires describing challenges with standard real options parameters and structures (Miller & Lessard, 2000). This can improve managerial understanding of the risk and prepare for risk management strategy design. Option design is improved by assessing and selecting individual and interacting sets of option parameters and their values, such as evaluating the exercise cost that would make an option very attractive or never beneficial. Operationalizing real option components such as operational changes required to change strategies and implement project monitoring signals improves option implementation. Through these means, real options can improve program planning and management by helping managers recognize, design, and use flexible alternatives to manage dynamic uncertainty.

Javelin Technology Options

As mentioned before, three teams were formed to develop competing guidance technologies for the Javelin. Only one team would then be chosen for follow-on advanced development and then production. Ford Aerospace was teamed with its partner Loral Systems, offering the laser-beam riding (LBR) missile. Hughes Aircraft was teamed with Boeing, offering a fiber-optic (FO) guided missile. Texas Instruments was teamed with Martin Marietta, offering an imaging infrared or forward looking infrared (FLIR) missile system. With the laser-beam riding system, the gunner would identify the target visually and point a laser beam at the target throughout flight. After launch, the missile continuously corrected its flight to match the line of the laser (to “ride” the laser beam) to the target. The optical fiber system included a coil of very long and fine optical fiber that connected the launch unit, operated by the gunner, to a camera in the nose of the missile. The gunner would fly the missile to the target using a joystick controller device. The FLIR scanned the

view in front of the gunner and generated a thermal-based image of the target area. Once observed through the Command Launch Unit, or thermal sight, the gunner switched to a starting array in the missile to acquire the target by narrowing brackets in the viewfinder around the target with a simple thumb switch. After launch, the missile would continuously correct its flight path using a tracking algorithm that employed optical correlators oriented upon visible and distinct target features.

Each of the teams enjoyed generally successful missile flight test outcomes as the proof of principle phase ended after 27 months. Each flew over a dozen missiles and achieved a target hit rate of over 60%. Each candidate system had specific advantages and disadvantages:

- The Ford/Loral Laser-Beam Rider required an exposed gunner and man-in-loop throughout its rapid flight. It was cheapest at an estimated $90,000 cost per kill, a figure that was comprised not only of average unit production cost estimates but also reliability and accuracy estimates. It was fairly effective in terms of potential combat utility, with diminishing probability-of-hit at increasing range. Top-attack on armor would be dependent upon precision fusing and detonation and accuracy of downward-firing explosively formed projectiles from shaped charges.

- The Hughes/Boeing Fiber-Optic guide prototype enabled an unexposed gunner (once launched) and also required man-in-loop throughout its slower flight. It was judged as likely costlier but less affected by accuracy throughout range with its automatic lock and guidance in its terminal stage of flight—and it even offered target switching. It was also more gunner training (learning) intensive but could attack targets from above, where the armor is thinnest.

- The FLIR prototype offered completely autonomous fire and forget flight to target after launch but was perceived as both the costliest and the technologically riskiest alternative. It was going to be easiest to train and would be effective to maximum ranges by means of its target

acquisition sensor and guidance packages. It used “top attack” as a more effective means of armored target defeat, but would also have a flat trajectory capability for “direct fire” against targets under cover of bridges, trees, and so forth.

Effectiveness of Technology Options

To evaluate the effectiveness of each alternative, we can use a simple hierarchical model based on the acquisition objectives identified for the anti-tank missile—lethality, tactical advantage, gunner safety, and procurement.[1] Our multi-criteria effectiveness model is based on concepts developed by decision analysts (see, for example, Buede, 1986; Keeney, 1982; and Keeney, 1988). The first three objectives deal with the operational effectiveness of the missile, while procurement recognizes that there are transaction costs and technology issues that make some alternatives easier to procure than others. Under each objective, there are metrics we can use to measure how well the objective is achieved. The objectives and corresponding metrics (measures) are shown in Table 1.

The relative importance of objectives and the relative importance of each measure with respect to an objective are shown in Table 1 by the weight assigned to each objective and measure. In our notional example, lethality, tactical advantage and gunner safety are each equally important but three times as important as procurement, so they are each assigned a weight of 0.3 while procurement receives a weight of 0.1. All the weights at each level of the hierarchy add up to one. For lethality, the relative importance of probability of a hit and kill or P(H)*P(K) is 0.7 compared to top-attack capability (0.3). For tactical advantage, the most important attribute is weight (0.4), followed by time to engage (0.3), then time of flight (0.2) and redirect capability (0.1). Gunner safety is measured by the amount of training required (0.2) and the gunner’s exposure to enemy fire after launch (0.8).

[1] The Services procuring the Javelin system did not actually use this exact methodology for the selection of the Javelin guidance technology but used something similar for a weighted decision analysis of the three alternatives.

Table 1. Anti-Tank Missile Guidance System Effectiveness

weight	objective	weight	measure	LBR		FO		FLIR	
				value	score	value	score	value	score
0.3	Lethality								
		0.7	P(H)*P(K)	5	1.05	4	0.84	7	1.47
		0.3	Top attack	6	0.54	7	0.63	9	0.81
0.3	Tactical Advantage	1							
		0.4	Weight	9	1.08	5	0.6	3	0.36
		0.3	Time to engage	8	0.72	7	0.63	5	0.45
		0.2	Time of flight	7	0.42	5	0.3	5	0.3
		0.1	Redirect capability	10	0.3	10	0.3	0	0
0.3	Gunner safety	1							
		0.2	Required training	5	0.3	1	0.06	10	0.6
		0.8	Exposure after launch	2	0.48	8	1.92	10	2.4
		1							
0.1	Procurement	1	Ease of procurement	8	0.8	6	0.6	4	0.4
1	**MOE**				**5.69**		**5.88**		**6.79**

The metric values achieved by each technology are converted to a notional value on a scale of 0 to 10, indicating the value the Army assigned to the actual level of performance. For example, the weight of a missile would be measured in pounds, with lighter systems preferred over heavier systems. In Table 1, the LBR system is the lightest and receives a value of 9, followed by the FO system which receives a value of 5. The FLIR system is the heaviest and receives the lower value of 3. For gunner safety, we want to minimize the amount of time the gunner is exposed to enemy fire (measured in minutes). For LBR, the gunner must stay in place until the target is hit, leading to a longer exposure time, so the LBR receives a low value of 2. The FO systems allows the gunner to hide while guiding the system, so he is exposed for a shorter time, and thus the FO system receives a better value of 8. The FLIR system allows the gunner to conceal himself immediately after launch (fire and forget). Thus, it is given the maximum value of 10. The other values shown in Table 1 are derived in a similar fashion.

A notional measure of effectiveness achieved by each of the three alternatives is shown at the bottom of Table 1. The scores shown in Table 1 for each metric (measure) are calculated by multiplying the value for the measure times the weight for that measure times the objective weight. For example, required training has a weight of 0.2 and is a metric that supports gunner safety which has a weight of 0.3. LBR received a value of 5 for this metric, so the score for LBR is 0.3 = (5) ×

(0.2) × (0.3). The score for FO is 0.060 = (1) × (0.2) × (0.3) and the score for FLIR is 0.6 = (10) × (0.2) × (0.3). All other scores in Table 1 are calculated in a similar manner. The MOE for any given alternative is the sum of the individual metric scores. For example, the MOE for LBR is 5.69 = 1.05 + 0.54 + 1.08 + 0.72 + 0.42 + 0.30 + 0.30 + 0.48 + 0.80. Note that the MOE is calculated on a scale of 0 to 10 where an "ideal" alternative would receive an MOE of 10. The notional MOEs in Table 1 are consistent with the Army's preference for the three guidance technologies, in that the Army preferred FLIR over the other two guidance systems and perceived the FO system as being slightly better than the LBR system.

Cost-Effectiveness Analysis

The previous section considered only the relative effectiveness of the three guidance alternatives. To select the best alternative, we have to also consider the development and procurement costs. The Army estimated the cost per kill for each alternative as shown in Table 2. We also show an estimate of the total program cost for each alternative in Table 2 assuming 2,000 missiles are procured.

Table 2. Anti-Tank Missile Cost

	LBR	FO	FLIR
Cost/kill ($M)	$0.09	$0.11	$0.15
Program Cost ($M)	$180	$220	$300

A cost versus effectiveness graph is shown in Figure 3. The total program cost and MOE for each alternative is shown on the graph.

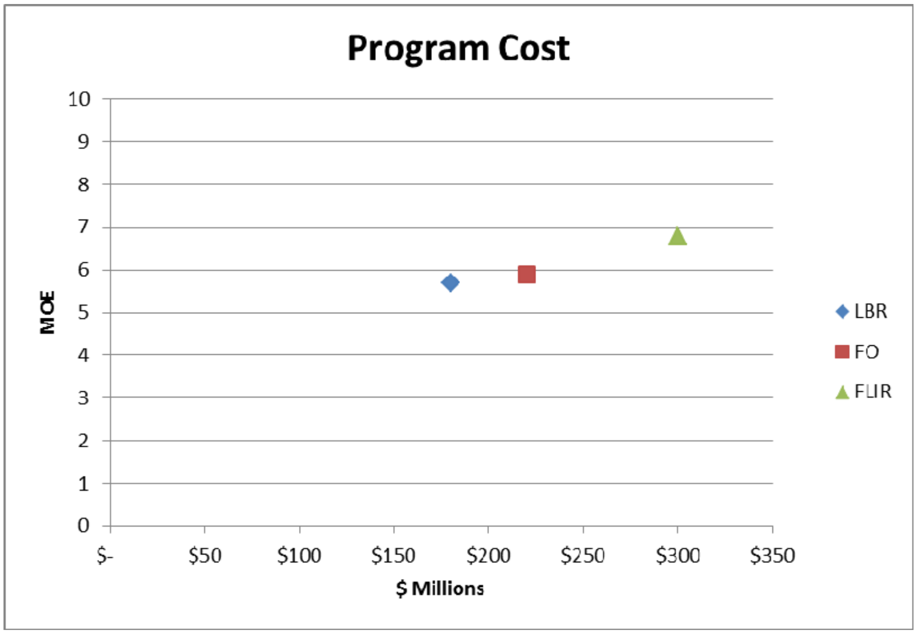

Figure 3. Anti-Tank Missile Total Program Cost vs. Effectiveness

From Figure 3, we can see that no alternative dominates another, meaning there is no alternative that is both cheaper and more effective than another. Thus, we must look at the marginal benefit and marginal cost to evaluate the alternatives. The LBR alternative is the least costly and least effective. We compare it to the FO alternative in Table 3 and note that the marginal cost of choosing FO over LBR is $40 million. Table 3 also shows the difference in values for each of the effectiveness measures used to calculate the MOE between the two alternatives. A positive change represents an increase in effectiveness, while a negative difference indicates a decrease in effectiveness. A similar analysis for FO versus FLIR is shown in Table 4.

Table 3. **Marginal Analysis of Cost and Effectiveness for LBR and FO**

Marginal Analysis	LBR	FO	Difference
Program Cost ($M)	$180	$220	$ 40
P(H)*P(K)	5	4	-1
Top attack	6	7	+1
Weight	9	5	-4
Time to engage	8	7	-1
Time of flight	7	5	-2
Redirect capability	10	10	0
Required training	5	1	-4
Exposure after launch	2	8	+6
Ease of procurement	8	6	-2

Table 4. **Marginal Analysis of Cost and Effectiveness for FO and FLIR**

Marginal Analysis	FO	FLIR	Difference
Program Cost ($M)	$220	$300	$ 80
P(H)*P(K)	4	7	+3
Top attack	7	9	+2
Weight	5	3	-2
Time to engage	7	5	-2
Time of flight	5	5	0
Recall capability	10	0	-10
Required training	1	10	+9
Exposure after launch	8	10	+2
Ease of procurement	6	4	-2

While Figure 3 gives us an overall picture of the cost versus effectiveness of the three alternatives, Tables 3 and 4 allow us to see what is gained and lost at the margin when going from one technology to the next. Arguably this is captured in the overall MOE, but decision-makers are often interested in seeing what specifically they are getting for their money. In addition, because the MOE is a combination of different metrics that are not necessarily interchangeable, it would not make sense to simply calculate the ratio of MOE to cost. Instead, the marginal analysis defines the trade-off space, but not the solution, for the decision-makers.

The previous cost versus effectiveness analysis assumed that all the guidance technology development efforts would be equally successful and achieve the calculated MOEs. But at the start of the proof of principle effort, there was no assurance that any of the technologies would be successfully developed. In fact, the probability of success differed between the three alternatives. A notional assessment of the probability of success for each option is given in Table 5.

Table 5. Probability of Development Success and Expected MOE for Javelin Technology Options

	LBR	FO	FLIR
P(success)	0.6	0.5	0.4
Expected MOE	3.414	2.94	2.716

Table 5 also shows the expected MOE based on the given probability of success for each option. The expected MOE is simply the MOE shown in Table 1 multiplied by the probability of success. Using the expected MOE, we can develop a revised cost versus effectiveness graph, as shown in Figure 4.

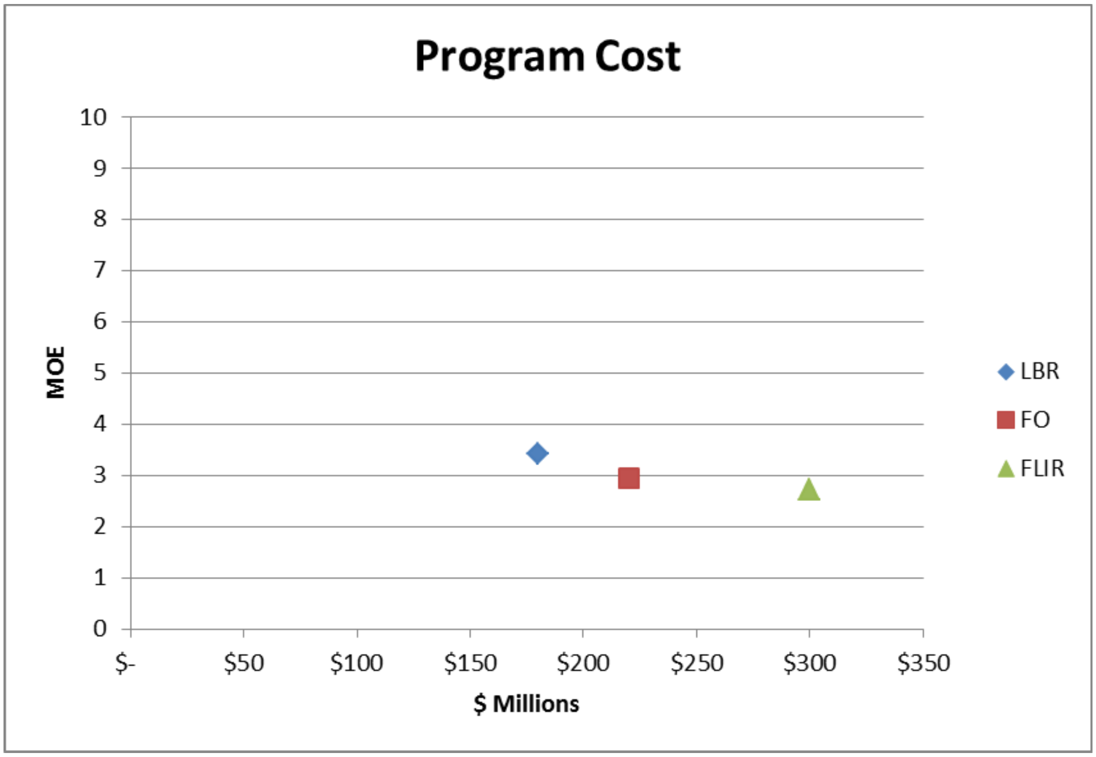

Figure 4. Anti-Tank Missile Total Program Cost vs. Effectiveness

Using the expected MOE, we see that both the FO and FLIR guidance systems are dominated by the LBR system, since it is both cheaper and has a higher expected MOE. (As it turned out, the Army's actual Cost and Operational Effectiveness Analysis [COEA] also found that the LBR was the preferred alternative.)

Value of Technology Options

The value of a real option is derived from the difference between the expected net value (benefits minus costs) of an investment and the net value of that investment given that it succeeds. The option value lies in the flexibility to terminate the project if it is not successful. To develop a simple option valuation model for the Javelin guidance technologies, we note that the benefits are given by the MOE as shown in Table 1. If we do not use a real option approach, then each of the alternatives has an expected cost based on the uncertainty associated with the technology development. If the development effort fails, we assume the Army will have to pay some additional cost to finish developing the technology and achieve

the anticipated level of effectiveness (MOE). We refer to this additional cost as the "cost to fix" the technology. If the technology development phase is successful, then the cost to exercise the option will be the total program cost from Table 2 and is shown as "cost to implement" in Table 6. If the technology development phase fails, the cost of the alternative will be the cost to implement plus the cost to fix the technology. The total expected cost of each alternative is given in Table 6.

Table 6. Expected Cost of Javelin Guidance Technology Alternatives Without Option to Terminate Project

	LBR	FO	FLIR
Probability of success	0.6	0.5	0.4
Cost to implement	180	220	300
Probability of failure	0.4	0.5	0.6
Cost to fix	*50*	*70*	*90*
Total cost to implement given failure	230	290	390
Expected Cost	200	255	354

The values shown in Table 6 assume that decision-makers do not use a real options approach. Instead, they pick one of the technologies based on the cost versus benefit analysis presented in the previous section. Whichever technology is chosen, there is an additional cost to achieve the anticipated effectiveness (MOE) if the development phase fails.

Using a real options approach, the Army pays for the option to find out whether the technology development succeeds before making a final choice. If the development succeeds, we have achieved the MOE shown in Table 1 and can proceed with the project if we prefer that option (based on the cost versus effectiveness analysis presented in the previous section). If the development fails, we terminate the project and there is no further cost. The value of the option is given by the difference between the expected value of the project with no option (from Table 6) and the expected value of the project with the option to terminate. The calculations are shown in Table 7.

Table 7. Value of Javelin Guidance Technology Options

	LBR	FO	FLIR
Probability of success	0.6	0.5	0.4
Cost to implement	180	220	300
Probability of failure	0.4	0.5	0.6
Cost if project is terminated	0	0	0
Expected cost with option	108	110	120
Expected cost w/o option	200	255	354
Value of option	92	145	234

The values of the options for each alternative are different because there are different levels of uncertainty associated with each technology. Given that we are willing to pay for the technology with no options, the more uncertain the technology, the more we value the option to terminate the project if the technology development fails. The values shown in Table 7 are maximums in the sense that if we pay any more than the option value, we would have been better off not using an option. If we pay less than the option value, we experience real cost savings by not expending funds on an unsuccessful technology.

Suppose the Army preferred the LBR technology (based on the cost versus effectiveness analysis presented in the previous section). They should pay no more than $92 million for the option to terminate the project. But the Army was buying options for all three technologies, so the total amount that they spend on options should not exceed the value of the option for the preferred technology. Since the value of the LBR option is $92 million, if they allocated the option value equally across all the alternatives, they should spend no more than about $30 million for each option, which is exactly what they did.

But allocating the option value equally across the alternatives does not make sense, given that some technology is more uncertain that others. It would make more sense to allocate the option value based on the level of uncertainty that we are

trying to resolve. Using the probability of failure in Table 7 as a notional measure of risk, we can allocate the option value in proportion to that risk, giving 27% of the total option value to LBR, 33% to FO, and 40% to FLIR. Going back to our previous example, if the Army prefers the LBR technology, then the total cost of the option should not exceed $92 million. That means the Army should pay about $25 million for the LBR option, $30 million for the FO option, and $37 million for the FLIR option. Doing so allocates the dollars based on risk while keeping the total cost equal to the option value of the preferred alternative. Again, we note that $92 million is a maximum. To realize any cost savings from the option, the Army must pay less than $92 million for all three options.

The Army's Choice

The laser-beam rider candidate emerged the winner of the COEA based on weighted cost/efficiency factors. But in a strange twist, the concurrent deliberation of the Source Selection Evaluation Board (SSEB) instead chose the FLIR candidate because of a bias toward fire and forget. As part of the capability formulation process, technical constraints are deliberately avoided in requirements documents, to allow and encourage a maximum range of alternative solutions to the need or capability deficiency. Although time of flight and gunner survivability were not stated requirements in the AAWS–M Joint Required Operational Capability document per se, fire and forget nevertheless translated into greatly enhanced gunner survivability and overwhelmingly appealed to user representatives.

In June 1989, a full-scale development (now called Engineering and Manufacturing Development) contract was awarded for the AAWS–M project to the Joint Venture team of Texas Instruments and Martin Marietta. At the macro level, the office of the Secretary of Defense viewed the program as acceptable with regard to risk because of its 27-month technology development phase, use of real options for a technical solution, and subsequent 36-month plan for full-scale development. But at the program office level, it was known to be one of high risk in several technical areas. Focal plane array (FPA) technology was still immature and would be gauged today at approximately Technology Readiness Level 5, despite its successful

technology-development phase results. It was always recognized as technologically risky, so the government funded its own night-vision laboratory to partially fund other companies that could produce these devices. In 1991, the only five known FPA makers in the world were Rockwell International, Loral, Santa Barbara Research Corporation, Sofradir (a French firm), and Texas Instruments.

The two-partner Joint Venture in the full-scale development phase was also free to maximize competition at the subcontractor level. In their make-versus-buy decision, Texas Instruments elected to make the focal plane array for both of its uses in the command launch unit and in the missile. The company had made these devices for other programs but not in these two distinct configurations (scanning and starting arrays).

As an additional gauge of technological maturity, a comparative baseline test was mandated at the second milestone upon the decision to launch the Javelin program into full-scale development. That test would pit the immature focal plane array technology against existing Tube-launched, Optically-tracked, Wire-guided (TOW) and Dragon (legacy systems) night-viewing optics. Results of this test showed the Javelin's immature focal plane arrays to be substantially better in performance than the Dragon and almost as effective as the much larger TOW anti-tank missile system.

About 18 months into the Engineering and Manufacturing Development (EMD) phase, serious technical problems around focal plane array attainment of specified sensitivity and production yield, system weight, tracker algorithm, and other areas doubled the expected cost of development and added about eighteen more months to the originally planned thirty-six months to complete. This constituted a Nunn–McCurdy breach of cost and schedule thresholds, with requisite Congressional notifications and formal re-baselining taking the better part of the next year to accomplish. Over that next year, the program sought a new baseline with many different revised program estimates—climbing from 36 months duration and $298 million in cost, to 48 months duration and $372 million in cost, and finally 54 months and $443 million for the total cost and duration of this phase. Within that

year, the program was restructured, given the new baseline, and finished largely within its new parameters. The additional eighteen months added to the 36-month phase helped resolve the uncertainties and complexities of system development without additional schedule slippage.

Today, Javelin is viewed as being a totally successful weapon system, despite its much earlier programmatic shortcomings in development. It is being used in combat operations and has continued through many full-rate production contract periods. Over 1,000 Javelin missiles have been fired in the Iraq War and Afghanistan since March 2003, with close to 98% reliability. The system design has continued to be upgraded—not as blocks of capability, but with software, warhead, and producibility enhancements.

Conclusions

Several observations can be made from our analysis of the Javelin guidance technology acquisition process. The first is that the benefit of weapon systems, or in this case missile guidance systems, is not measured in dollars. This makes using a traditional option valuation model (based on benefits minus costs) difficult. Instead, we must use the principles of multi-criteria decision-making to develop an MOE for each alternative. The MOE can be compared to the cost to define the trade space for the decision-maker.

Second, we note that the three proposed guidance technologies had different levels of risk. We use this information to calculate the expected MOE for each alternative, thus incorporating uncertainty into the analysis. The probabilistic MOE can be compared to the expected cost (in our case, cost per kill) to present a risk-adjusted trade space for the decision-maker.

Third, we show that a real options approach allows us not only to incorporate uncertainty in our analysis but also to calculate the value of the option based upon risk. This leads to different option values for different alternatives based on the technology maturity. Using this approach, the Army should have offered each development team a different amount of money to develop their proposed technology. Doing so would have better allocated the dollars to manage risk.

Finally, we note that the final cost to fix the FLIR guidance technology selected by the Army turned out to be significantly higher than the $30 million originally paid to develop the technology. This is in line with what our real options model suggested, since the FLIR technology was always anticipated to be the riskiest.

The use of real options models allows us to estimate the value of flexibility in acquisition decisions. Understanding this value allows program managers to assign program dollars based on risk and supports the efficient use of limited program resources.

References

Amram, M., & Kulatilaka, N. (1999). *Real options: Managing strategic investment in an uncertain world*. Cambridge, MA: Harvard Business School Press.

Brealey, R., & Myers, S. (2000). *Principles of corporate finance* (6th ed.). New York, NY: McGraw–Hill.

Buede, D. M. (1986). Structuring value attributes. *Interfaces, 16*(2), 52–62.

Ceylan, B. K., & Ford, D. N. (2002). Using options to manage dynamic uncertainty in acquisition projects. *Acquisition Review Quarterly, 9*(4), 243–258.

Courtney, H., Kirkland, J., & Viguerie, P. (1997). Strategy under uncertainty. *Harvard Business Review, 75*(6), 67–79.

Dillard, J., & Ford, D. (2009). From amorphous to defined: Balancing the risks of spiral development. *Acquisition Review Journal, 52*, 236-252.

Ford, D., & Dillard, J. (2009). Modeling the Performance and Risks of Evolutionary Acquisition. *Acquisition Review Journal, 51,* 143-158.

Garvin, M., & Cheah, C. (2004). Valuation techniques for infrastructure decisions. *Construction Management & Economics, 22*(5), 373–383.

Garvin, M., & Ford, D. (2012, January 24). Real options in infrastructure projects: Theory, practice and prospects. *Engineering Project Organization Journal*, *2*(1-2), 97–108.

Keeney, R. (1982). Decision analysis: An overview. *Operations Research, 30*(5), 803–838.

Keeney, R. (1988). Structuring objectives for problems of public interest. *Operations Research, 36*(3), 396–405.

Lyons, J., Long, D., & Chait, R. (2006). *Critical technology events in the development of the Stinger and Javelin Missile Systems, project hindsight revisited.* Washington, DC: National Defense University, Center for Technology and National Security Policy.

Miller, R., & Lessard, D. (2000). *The strategic management of large engineering projects*. Cambridge, MA: MIT Press.

Triantis, A. (2005). Realizing the potential of real options: Does theory meet practice? *Journal of Applied Corporate Finance, 17*(2), 8–16.

THIS PAGE INTENTIONALLY LEFT BLANK

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL
555 DYER ROAD, INGERSOLL HALL
MONTEREY, CA 93943

www.acquisitionresearch.net